

3.1.3 RF Power Source

3.1.3.1 Overview

The RF source for the 400-MeV linac is required to power twenty accelerating cavity modules (an RFQ, 3 DTLs and 16 SDDL modules) operated at a frequency of 324 MHz, and twenty-three ACS modules operated at a frequency of 972 MHz. For buncher, chopper and debuncher cavities, furthermore, three 324-MHz RF sources and four 972-MHz RF sources are required. These RF sources must maintain the correct accelerating field within an amplitude error of $\pm 1\%$ and a phase error of $\pm 1^\circ$, so that a digital feedback and feed-forward control system with high intelligence is required. To achieve requirements of both the RCS and the ADS, the maximum pulse width and repetition rate are 620 μs , including the cavity build-up time, and 50 pps, respectively.

RF System

The RF system for the 400-MeV linac is shown in Fig. 3.1.3.1, and consists of the following subsystems:

1. RF Drive System (Reference Signal Distribution and Amplifier Driver)

The drive system distributes a 12-MHz master clock signal to all of the power amplifier stations (4 solid states and 46 klystrons) and drives these amplifiers, which will be installed in the klystron gallery with a total length of about 300 m. The accelerating frequency signal of 324 MHz or 972 MHz is generated at the front-end of each amplifier station by a voltage controlled oscillator (VCO), which is phase locked with the distributed 12-MHz signal.

2. Low Level RF Control System (Field Stabilizing Feedback Control)

To stabilize an amplitude and phase of the field in the accelerating cavity the feedback and feed-forward technique is used in the low level RF control system. The feedback and feed-forward control is performed by a combination of FPGAs (field programmable gate array) for fast and simple processing and DSPs (digital signal processor) for slow and complicate processing. At the present stage, a compact PCI bus and Windows OS system is used as an integrated development environment in order to make it easy for us to develop the software of FPGAs, DSPs and a CPU, although a VME bus and VxWorks OS system is more reliable and suitable for the EPICS network and computer system.

3. Solid State Power Amplifiers

Slid state power amplifiers are adopted for power sources of the required

output power of less than 30 kW. There are four amplifiers: two 10-kW 324-MHz amplifiers for the buncher-1 and the buncher-2; one 30-kW 324-MHz amplifier for the chopper; and one 30-kW 972-MHz amplifier for the debuncher-2.

4. Klystrons

Twenty 3-MW 324-MHz klystrons will be used in the first half on the linac (an RFQ, three DTLs and sixteen SDDL modules), and twenty-six 3-MW 972-MHz klystrons will be used in the latter half of the linac (buncher-3, buncher-4, twenty-three ACS modules, and debuncher-1). The 324-MHz klystron will be installed in horizontal position in an equal space of 6.5 m along the klystron gallery, and the 972-MHz klystron will be installed in vertical position in an equal space of 4.8 m along the klystron gallery.

5. Klystron Power Supplies

The basic configuration of the klystron high-voltage (HV) dc power supply is that one common dc power supply equipped with a crowbar protection circuit supplies four klystrons with the same cathode voltage. Each klystron has a modulator for the modulating anode and low-voltage power supplies for such as a heater, an ion pump and focusing coils. The first HV dc power supply (HVDC-01) for RFQ and 3 DTL klystrons is composed of three normal output ports with a crowbar and one lower-voltage output port without a crowbar. The HV dc power supplies of HVDC-06 for buncher-3 and buncher-4 klystrons, and HVDC-13 for the debuncher klystron are different ones from other regular power supplies: an 80-kV output voltage, two ports with a crowbar.

6. Waveguide System

The 324-MHz waveguide system is composed of WR-2300 full-height waveguide components (a circulator, a 3-dB power divider, a ± 30 -degree phase shifter), which will be installed in the klystron gallery, and WR-2300 half-height waveguide components that penetrate from the klystron gallery to the tunnel. At the floor level of the tunnel, the half-height waveguide is translated to a coaxial transmission line of WX-203 to connect a cavity input coupler. The 972-MHz waveguide system is composed of WR-975 waveguide components all along the line from a klystron output port to a cavity input coupler.

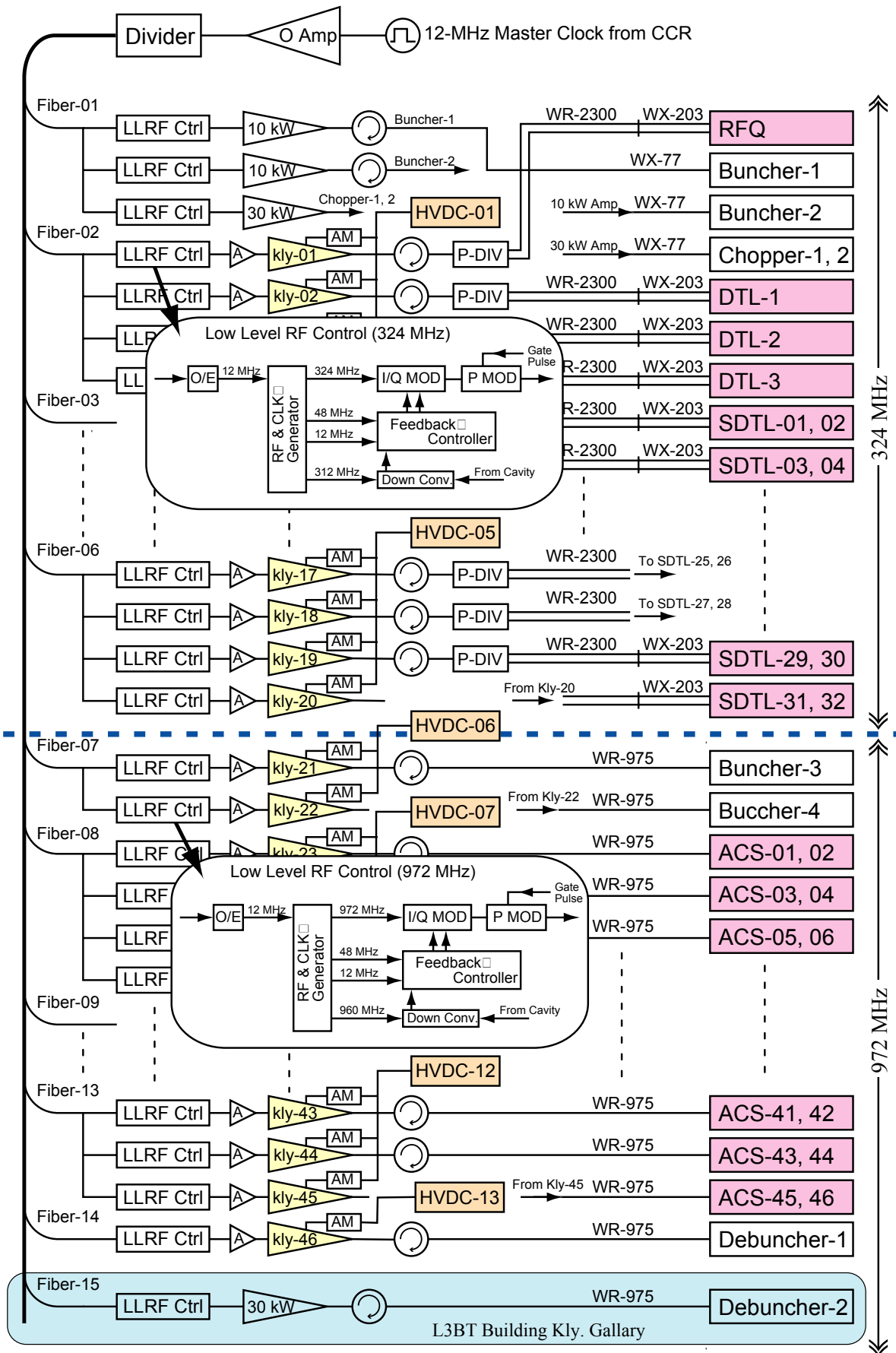


Fig. 3.1.3.1 RF system for the 400-Mev linac

Peak Power Requirements

The peak power (“Excitation”, “Beam” and “Total”) summarized in Table 3.1.3.1.1 is increased 1.11 ($=1/0.9$) times as much as the power required from each cavity or two-cavity module, taking account of losses in the waveguide system (maximum 10% loss). “Beam” in this table shows a beam loading compensation power when accelerating a beam current of 50 mA without beam chopping, corresponding to a peak current of 89 mA with 56% beam chopping. In order to enable to stabilize the accelerating field in the tank, the klystron must be operated within an unsaturated region, and then the output power must be controlled by the input power level. We will therefore set as a working point the cathode voltage at which the klystron is capable of outputting 1.11 times as much as the required power (“Total” in this table) when the klystron is saturated.

Main Parameters

Main parameters of the RF source are summarized in Table 3.1.3.1.2.

The maximum RF pulse width is mainly limited by the average output current of the HV dc power supplies, so that in case of operation at a low pulse repetition rate (25 Hz) we can widen the pulse width, as long as the required cathode voltage that must be increased for compensating the voltage drop due to a sag, which is proportional to the current pulse width, does not exceed a 110-kV maximum output voltage of the power supply, as well as the klystron can withstand for that cathode voltage.

The solid state amplifiers used are based on the TV broadcasting model, thus, they have the high reliability and the high-duty factor operation capability.

The HV dc power supplies for all of the DTLs, SDTLs and ACSs have the same output capacity: 110 kV dc, 45 A peak and 50 pps, although each of them requires the different and lower RF power. All of the HV dc power supplies will therefore be operated at a low rating and with a large margin. Adjustments of working points for four klystrons connected with the common HV dc power supply are made by changing the output pulse voltage of the modulating anode modulators. The output pulse voltage of the modulating anode modulator can be adjusted by changing a dividing ratio of the anode resistor of a HV switching device.

Table 3.1.3.1.1. Peak power requirements and klystron working points.

Cavity	Freq. (MHz)	Klystron Number	HVDC Number	Excitation (MW)	Beam (MW)	Total (MW)	Working point (MW)
RFQ	324	Klystron-01	HVDC-01	0.44	0.16	0.61	0.68
Buncher-1		(Solid State)	-	-	-	10 kW	-
Buncher-2		(Solid State)	-	-	-	10 kW	-
Chopper-1 & 2		(Solid State)	-	-	-	30 kW	-
DTL-1		Klystron-02	HVDC-01	1.18	0.93	2.11	2.34
DTL-2		Klystron-03		1.30	0.94	2.25	2.49
DTL-3		Klystron-04		1.19	0.74	1.93	2.14
SDTL-01 & 02		Klystron-05	HVDC-02	0.39	0.30	0.70	0.77
SDTL-03 & 04		Klystron-06		0.48	0.34	0.82	0.91
SDTL-05 & 06		Klystron-07		0.59	0.38	0.97	1.08
SDTL-07 & 08		Klystron-08		0.73	0.42	1.15	1.28
SDTL-09 & 10		Klystron-09	HVDC-03	0.89	0.46	1.36	1.51
SDTL-11 & 12		Klystron-10		1.12	0.52	1.63	1.81
SDTL-13 & 14		Klystron-11		1.18	0.52	1.70	1.89
SDTL-15 & 16		Klystron-12		1.23	0.53	1.77	1.96
SDTL-17 & 18		Klystron-13	HVDC-04	1.29	0.54	1.83	2.03
SDTL-19 & 20		Klystron-14		1.35	0.54	1.89	2.10
SDTL-21 & 22		Klystron-15		1.40	0.54	1.95	2.16
SDTL-23 & 24		Klystron-16		1.46	0.54	2.00	2.22
SDTL-25 & 26		Klystron-17	HVDC-05	1.51	0.54	2.05	2.28
SDTL-27 & 28		Klystron-18		1.56	0.54	2.10	2.34
SDTL-29 & 30		Klystron-19		1.61	0.54	2.15	2.39
SDTL-31 & 32		Klystron-20		1.65	0.54	2.19	2.44
Buncher-3	972	Klystron-21	HVDC-06	0.61	-	0.61	0.67
Buncher-4		Klystron-22		0.61	-	0.61	0.67
ACS-01 & 02		Klystron-23	HVDC-07	1.56	0.44	2.00	2.22
ACS-03 & 04		Klystron-24		1.56	0.45	2.01	2.23
ACS-05 & 06		Klystron-25		1.55	0.45	2.01	2.23
ACS-07 & 08		Klystron-26		1.55	0.46	2.01	2.24
ACS-09 & 10		Klystron-27	HVDC-08	1.55	0.47	2.02	2.24
ACS-11 & 12		Klystron-28		1.55	0.47	2.03	2.25
ACS-13 & 14		Klystron-29		1.55	0.48	0.03	2.26
ACS-15 & 16		Klystron-30		1.55	0.49	2.04	2.26
ACS-17 & 18		Klystron-31	HVDC-09	1.55	0.49	2.05	2.27
ACS-19 & 20		Klystron-32		1.55	0.50	2.05	2.28
ACS-21 & 22		Klystron-33		1.56	0.50	2.06	2.29
ACS-23 & 24		Klystron-34		1.56	0.51	2.07	2.30
ACS-25 & 26		Klystron-35	HVDC-10	1.56	0.51	2.07	2.30
ACS-27 & 28		Klystron-36		1.56	0.52	2.08	2.31
ACS-29 & 30		Klystron-37		1.57	0.52	2.09	2.32
ACS-31 & 32		Klystron-38		1.57	0.53	2.10	2.33
ACS-33 & 34		Klystron-39	HVDC-11	1.57	0.53	2.10	2.34
ACS-35 & 36		Klystron-40		1.58	0.54	2.11	2.35
ACS-37 & 38		Klystron-41		1.58	0.54	2.12	2.36
ACS-39 & 40		Klystron-42		1.58	0.55	2.13	2.36
ACS-41 & 42		Klystron-43	HVDC-12	1.59	0.55	2.14	2.37
ACS-43 & 44		Klystron-44		1.59	0.56	2.14	2.38
ACS-45 & 46		Klystron-45		1.59	0.56	2.15	2.39
Debuncher-1		Klystron-46	HVDC-13	0.22	-	0.22	0.25
Debuncher-2		(Solid State)	-	-	-	30 kW	-

Table 3.1.3.1.2. Main Parameters of RF source

Operation frequency	(MHz)	324		972
RF pulse width for excitation	(μ s)			max. 620
RF pulse width for beam acceleration	(μ s)			max. 500
Pulse repetition rate	(pps)			max. 50
Solid state amplifier				
Output power for buncher-1, 2		10 kW, 2 amps.		-
Output power for chopper-1, 2		30 kW, 1 amp.		-
Output power for debuncher-2		-		30 kW, 1 amp.
Klystron				
Number of klystrons		20		26
Output power (controllable by input power)	(MW)			max. 2.25
Output power saturated at working point	(MW)			max. 2.5
Beam voltage (including 5% sag)	(kV)			max. 107
Beam current	(A)			max. 45
Modulating-anode voltage	(kV)			max. 86
HV dc power supply				
Number of dc power supplies		5 (#1, #2 to #5)		8 (#6, #7 to #12, #13)
Number of klystrons per power supply				
#1 to #5 and #7 to #12				4
#6 (for bunchers) and #13 (for debuncher)				2
Output voltage (capability, not operated value)				
#1	(kV)	80 & 110 (3 para.)		-
#2 to #5 and #7 to #12	(kV)			110 (4 para.)
#6 and #13	(kV)	-		80 (2 para.)
Output current (capability, not operated value)				
#1	(A)	30 + 135		-
#2 to #5 and #7 to #12	(A)			180
#6 and #13	(A)	-		60
Modulating anode modulator				
Number of modulators		20		26
Output voltage range		70% ~ 90% of cathode voltage		
Pulse width range	(μ s)			100 ~ 800
Power feeder from klystron to cavity				
Waveguide		WR-2300 full and half		WR-975 full
Coaxial line for input coupler		WX-203		-
Circulator		WR-2300, Y-Junction		WR-975, Y-junction
Power divider (± 0.2 dB variable)		slot coupled		-
Terminator for circulator and power divider		resistor, WX-240		water, WR-975
Drive System				
Master oscillator frequency	(MHz)			12
Reference distribution line				Optical fiber
Local frequency generator				PLL VCO
RF and clock frequencies	(MHz)	12, 48, 312, 324		12, 48, 960, 972
Low level RF control				digital feedback and feed-forward
Inter mediate frequency	(MHz)			12
AD/DA sampling frequency	(MHz)			46